



## Spatio-Temporal Dynamics of Bloody Diarrhea Syndrome in Iran: A County-Level Identification of Clusters, Hot Spots, Outliers, and Seasonal Trends (2015–2019)

Dariush Bastam<sup>1</sup>, Manoochehr Karami<sup>2,3</sup>, Mahshid Nasehi<sup>1</sup>, Masoud Salehi<sup>4</sup>, Alireza Amouzandeh Nobaveh<sup>5</sup>, Mohammad Zeinali<sup>6</sup>, Babak Eshrati<sup>7,8\*</sup> 

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### Abstract

**Background:** Bloody diarrhea remains a significant public health challenge in developing countries. Despite general improvements in health indicators, Iran continues to experience geographical disparities in the incidence of foodborne and waterborne diseases. This study aimed to analyze spatiotemporal patterns, identify high-risk clusters, and detect local outliers of bloody diarrhea across all counties in Iran over a five-year period.

**Methods:** This retrospective ecological study was conducted using data from the National Surveillance System on 62,787 confirmed cases of bloody diarrhea from 2015 to 2019. The unit of analysis was the county level. The Global Moran's I index was employed to test for spatial autocorrelation. Local spatial patterns were examined using the Getis-Ord Gi\* statistic (Hot Spot Analysis) and Anselin Local Moran's I (Cluster and Outlier Analysis) in ArcGIS 10.4. Temporal trends were evaluated using deseasonalized time-series analysis.

**Results:** The overall incidence rate showed a mild downward trend with a distinct seasonal peak in May (mid-spring). The disease predominantly affected children under 9 years of age (51.3%) and males (54.1%). Global spatial analysis confirmed significant clustering in all years except 2016. Hot spot analysis revealed a geographical shift in high-risk areas: while intense but transient clusters were identified in central Iran (Isfahan and Chaharmahal and Bakhtiari) only in 2015 (coinciding with a major outbreak), persistent high-risk clusters were established in the southeastern and eastern provinces from 2017 to 2019. Notably, the Anselin Local Moran's I test identified several "High-Low" outliers, indicating isolated local outbreaks within low-risk regions.

**Conclusion:** The epidemiology of bloody diarrhea in Iran is characterized by a dual pattern: transient epidemic outbreaks in central/tourist regions and chronic endemicity in underdeveloped southeastern border areas. The findings indicate a spatial transition of the disease burden toward the southeast. Effective control strategies should prioritize infrastructure development in the endemic eastern belt and the implementation of targeted syndromic surveillance in identified outlier hot spots to manage seasonal outbreaks.

**Keywords:** Bloody Diarrhea, Time Series, Spatio-Temporal Analysis, Cluster Analysis, Iran

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**Corresponding author:** Dr Babak Eshrati, [eshrati.b@iums.ac.ir](mailto:eshrati.b@iums.ac.ir)

1. Department of Epidemiology, School of Public Health, Iran University of Medical Sciences, Tehran, Iran

2. Pandemic and Epidemic Preparedness and Response Research Network, Research Institute for Health Sciences and Environment, Shahid Beheshti University of Medical Sciences, Tehran, Iran

3. Department of Epidemiology, School of Public Health and Safety, Shahid Beheshti University of Medical Sciences, Tehran, Iran

4. Department of Biostatistics, School of Public Health, Iran University of Medical Sciences, Tehran, Iran

5. Department of Infectious Diseases, School of Medicine, Firoozabadi Hospital, Iran University of Medical Sciences, Tehran, Iran

6. Head of National Department of Zoonotic Disease Control, Center for Communicable Diseases Control, Ministry of Health and Medical Education, Tehran, Iran

7. Department of Community and Family Medicine, School of Medicine, Iran University of Medical Sciences, Tehran, Iran

8. Vaccine Research Center, Preventive Medicine and Public Health Research Center, Psychosocial Health Research Institute, Iran University of Medical Sciences, Tehran, Iran

### Key Messages:

#### ↑What is "already known" in this topic:

Dysentery syndrome remains a public health challenge in Iran. While routine surveillance data are collected annually, previous studies have mostly focused on clinical aspects or limited geographical areas, lacking a comprehensive national-level spatial analysis to identify high-risk clusters and local outliers over time.

#### →What this article adds:

This study provides the first county-level spatiotemporal analysis of bloody diarrhea in Iran (2015–2019). It identifies a geographical shift of disease incidence towards eastern and southeastern borders, while also detecting significant spatial outliers in central tourist areas. These findings enable policymakers to implement targeted, place-based interventions rather than uniform national strategies.

## Introduction

Diarrheal diseases remain a significant global public health challenge, contributing disproportionately to the burden of disease and preventable mortality, particularly among children under five years of age and the elderly in developing nations (1, 2). Among the various clinical manifestations of these enteric diseases, Bloody Diarrhea Syndrome (BDS) (Dysentery)—characterized by acute diarrhea with visible fecal blood—exhibits particular epidemiological relevance. This prominence is due to the aggressive pathogenicity of its etiological agents, the potential to trigger explosive outbreaks, and the association with severe sequelae, including severe dehydration, malnutrition, and Hemolytic Uremic Syndrome (HUS) (3-6).

Etiologically, while a range of bacterial, viral, and parasitic agents may induce bloody diarrhea, *Shigella* species are predominantly recognized as the primary drivers of both waterborne and foodborne outbreaks (4, 7). Estimates from the World Health Organization indicate that Shigellosis results in millions of incident cases and tens of thousands of fatalities annually, with the burden heavily concentrated in regions suffering from inadequate sanitary infrastructure (4, 6). The fecal-oral transmission route of this disease, together with its marked dependence on environmental, climatic, and socio-economic determinants, underpins the emergence of heterogeneous spatial patterns and distinct temporal and seasonal variations in disease incidence. Therefore, a detailed understanding of these spatiotemporal patterns is essential for the development of targeted interventions (3, 8-11).

In the Islamic Republic of Iran, despite improvements in health indicators, expanded access to safe drinking water, and strengthening of the Primary Health Care (PHC) network in recent decades, recurrent reports of dysentery outbreaks indicate that diarrheal diseases remain a persistent challenge for the national surveillance system. Effective control of these pathologies necessitates the formulation and execution of strategies rigorously aligned with local epidemiological dynamics (12, 13).

Local epidemiological patterns of diarrheal diseases are often influenced by regional determinants, including climatic variability, socioeconomic and cultural diversity, and disparities in health infrastructure (5, 14). This heterogeneity highlights the need for geography-based research to inform preventive strategies. Spatial epidemiology, utilizing Geographic Information Systems (GIS) and spatial statistics, functions as a powerful tool to move beyond mere data description, enabling a comprehensive analysis of the mechanisms underlying disease distribution (15).

The existing literature in Iran has predominantly focused on clinical and laboratory dimensions or has been restricted to cross-sectional analyses confined to specific temporal and geographical contexts (16-19). There is a notable deficiency of comprehensive investigations that employ a hierarchical approach—from the national to the local scale—capable of simultaneously identifying spatial clusters and outliers through the application of advanced indices. Mapping the geographical clustering of counties with elevated or diminished dysentery rates facilitates the

optimized allocation of resources and the formulation of region-specific control protocols. Moreover, the identification of spatial outliers—counties exhibiting high incidence rates adjacent to low-incidence areas (High-Low) and vice versa (Low-High)—is of paramount significance. These anomalous localities, often obscured in traditional aggregate analyses, may serve as sentinel indicators of emerging hotspots, common-source outbreaks, or "islands of success" in disease control, thereby providing a foundation for future inquiries into the determinants of efficacy or failure in public health interventions (20).

This study is designed to address a critical gap in the existing literature. Utilizing five years of longitudinal data (2015-2019) from the national syndromic surveillance system, this research aims to delineate the precise spatio-temporal characteristics of BDS across Iranian counties. By integrating time-series analysis—aimed at mitigating seasonal confounding and extracting secular trends—with advanced spatial analytics, including Global Moran's I, Getis-Ord  $G_i^*$ , and Anselin Local Moran's I, this study seeks to provide empirical evidence essential for policy-makers to prioritize resources, identify at-risk populations, and implement targeted place-based interventions.

## Methods

### Study Setting

This study was conducted in the Islamic Republic of Iran, which is situated within the Eastern Mediterranean Region as classified by the World Health Organization. The country is geographically positioned between latitudes 25° and 40° N and longitudes 44° and 64° E, covering an extensive area of 1,648,195 km<sup>2</sup>, with an estimated population of approximately 80 million as of 2016 (21).

Iran is administratively divided into 31 provinces and 462 counties.

A notable characteristic of the country is its considerable environmental and topographic diversity, with elevations reaching up to 5,671 meters above sea level and a climate that ranges from arid to subtropical. Annual precipitation varies significantly, from 100 to 2,000 mm, while temperatures can fluctuate between -10°C and 50°C. Iran shares land borders with Armenia, Azerbaijan, and Turkmenistan to the north; Afghanistan and Pakistan to the east; and Iraq and Turkey to the west. Additionally, it possesses maritime borders with the Caspian Sea to the north and the Persian Gulf and the Sea of Oman to the south (22).

### Study Design and Population

This study was designed as a retrospective ecological analysis conducted from March 21, 2015, to March 19, 2020. For clarity and consistency in reporting, these five annual periods are referred to as 2015–2019 throughout the manuscript. The spatial unit of analysis was the county, which represents the second-level administrative division in Iran. This unit was selected to ensure comprehensive territorial coverage, thereby facilitating a robust assessment of spatial heterogeneity.

The target population comprised all residents of Iran's counties during the study period. The study population included all clinically diagnosed cases of BDS reported by healthcare facilities or hospitals, provided that the dates of symptom onset fell within the temporal scope of the study. Cases with symptom onset dates outside this period or lacking county-level geographical information were excluded from the analysis.

#### Operational Case Definition

According to the standard definition of syndromes in the National Surveillance System of Iran, a case of BDS is defined as acute diarrhea characterized by the presence of visible blood in the stool, with or without accompanying symptoms such as nausea, vomiting, or abdominal cramping.

#### Data Acquisition and Pre-processing

Epidemiological data on registered cases of BDS were extracted from the National Notifiable Diseases Surveillance System of Iran's Center for Communicable Diseases Control (ICDC). As the most recent official national census was conducted in 2016, this year's population data served as the reference population. Populations for the other study years were estimated for each county using the annual population growth rate published by the Statistical Center of Iran.

To control for the confounding effect of population heterogeneity and to enable valid spatial comparisons, raw case counts were normalized. The annual incidence rate was calculated for each county as the number of new cases per 100,000 population, utilizing the estimated mid-year population as the denominator. Given that each individual was at risk for one year, the mid-year population serves as an appropriate proxy for person-years at risk.

A geospatial database was constructed in ArcGIS v10.4 (ESRI, Redlands, CA, USA) by linking the descriptive epidemiological data to a vector shapefile of Iran's county administrative boundaries.

#### Temporal Pattern and Seasonal Trend Analysis

To investigate temporal variations and seasonal patterns in disease incidence over the 60-month study period, a time-series analysis was employed. First, national monthly incidence rates were calculated. To smooth the data, a 12-month moving average followed by a centered moving average was applied. The long-term trend was estimated by modeling the deseasonalized data against time using linear regression. The incidence rate, centered moving average, and trend component were plotted to simultaneously examine seasonal fluctuations and the overall secular trend. All calculations and graphical representations for this analysis were performed using Minitab software (v21.3).

#### Spatial Pattern Analysis

A hierarchical approach, incorporating both global and local spatial analyses, was employed to examine spatial patterns and identify clusters of elevated dysentery inci-

dence. Spatial relationships among counties were delineated using a spatial weights matrix derived from a fixed distance band method, with distances computed based on the Euclidean distance between county centroids. All spatial analyses and result visualizations were conducted within the ArcGIS v10.4 environment.

#### Global Spatial Autocorrelation

As a first step, Global Moran's I statistic was employed to test the null hypothesis of complete spatial randomness (CSR) in the distribution of disease incidence across the country. This index assesses the presence or absence of a clustering pattern for the entire study area. A positive Moran's I value indicates a tendency toward clustering, a negative value suggests a tendency toward dispersion, and a value near zero implies a random spatial distribution. Statistical significance of the index was evaluated using Z-scores and P-values at 90%, 95%, and 99% confidence levels (23).

#### Local Indicators of Spatial Association (LISA)

Following the confirmation of a global spatial pattern, (LISA) was employed to pinpoint the precise locations of clusters and identify spatial heterogeneity at the county level. Specifically, two local techniques were applied.

1. Hot Spot Analysis (Getis-Ord  $G_i^*$ ). The Getis-Ord  $G_i^*$  statistic was used to detect statistically significant high-risk (hot spots) and low-risk (cold spots) clusters. This technique compares the local sum of values for a county and its neighbors to the global sum for the entire study area. The output of this analysis consists of maps where counties are color-coded based on their Z-scores at 90%, 95%, and 99% confidence levels (24).

2. Cluster and Outlier Analysis (Anselin Local Moran's I). As a complementary technique, this method was employed to distinguish between spatial clusters and spatial outliers. A spatial outlier is defined as a county whose incidence rate is statistically anomalous compared to that of its neighbors. This analysis classifies each county into one of five distinct categories based on its local Moran's I value, Z-score, and p-value (20, 25, 26):

High-High (HH) Cluster: A county with a high incidence rate surrounded by neighbors with high incidence rates (analogous to a hot spot).

Low-Low (LL) Cluster: A county with a low incidence rate surrounded by neighbors with low incidence rates (analogous to a cold spot).

High-Low (HL) Outlier: A county with a high incidence rate surrounded by neighbors with low incidence rates.

Low-High (LH) Outlier: A county with a low incidence rate surrounded by neighbors with high incidence rates.

Not Significant: A county exhibiting no statistically significant spatial pattern in relation to its neighbors.

#### Visualization

The results of the spatial analyses were visualized using choropleth maps to facilitate the interpretation of geographical patterns, clusters, and gradients in disease incidence.

## Results

During the 5-year study period (2015–2019), a total of 62,787 cases of BDS were recorded in the national surveillance system. The majority of cases were male (54.11%) and urban residents (65.45%). In terms of age, the highest frequency was observed in the <9-year group (51.29%), followed by the ≥60-year group (12.45%). By occupation, children under 6 years (43.26%) and homemakers (17.45%) accounted for the largest proportions (Table 1).

The annual incidence rate of BDS fluctuated from 2015 to 2019, with rates of 17.36, 14.03, 14.27, 18.05, and 13.90 per 100,000 person-years, respectively. Throughout the study period, the incidence was consistently higher among males than females (Figure 1).

### Temporal Trends and Seasonality

Analysis of deseasonalized monthly incidence indicated a slight downward trend over the study period. The trend equation ( $Y_t = 1.3669 - 0.00286 \times t$ ) confirmed this slight negative slope after adjusting for seasonality. A distinct seasonal pattern was observed, peaking in late spring (May) and reaching a trough in late winter (March). Figure 2 illustrates the deviation of raw incidence from the trend line, highlighting the magnitude of seasonal fluctuations (Figure 2).

### Geographical Heterogeneity in Incidence Rates

Descriptive spatial analysis indicated severe geographical heterogeneity in the distribution of disease incidence at the county level. As illustrated in Figure 3, the incidence range varied from near-zero values in some counties to over 1,500 cases per 100,000 population in specific regions. High-incidence counties were primarily concentrated in the southern, southeastern, and parts of the central regions of the country.

During the initial phase of the study (2015–2017), Khorrambid County in Fars province consistently exhibited the highest incidence rates nationally. Other high-burden areas during this period included Khonj, Faryab, Mehrestan, and Gerash. Subsequently, during 2018 and 2019, the geographical concentration of disease incidence clearly shifted toward the southeast of the country, with Mehrestan, Delgan, and Fanuj in Sistan and Baluchestan province, along with Nain in Isfahan, accounting for the highest annual incidence rates. Overall, although the descriptive maps show a general decreasing trend for the disease, the displacement of high-incidence counties among Fars, Kerman, and Sistan and Baluchestan provinces is evident (Figure 3).

### Global Spatial Autocorrelation

Global Moran's I analysis revealed significant positive

Table 1. Demographic distribution of patients with BDS in Iran

| Variable       |                                                | Number | Percent |
|----------------|------------------------------------------------|--------|---------|
| Gender         | Male                                           | 33,975 | 54.11   |
|                | Female                                         | 28,812 | 45.89   |
| Residence area | City                                           | 41,100 | 65.45   |
|                | Village                                        | 21,687 | 34.55   |
| Age group      | 1–9                                            | 32,196 | 51.29   |
|                | 10–19                                          | 6,713  | 10.69   |
|                | 20–29                                          | 6,120  | 9.75    |
|                | 30–39                                          | 5,698  | 9.08    |
|                | 40–49                                          | 3,777  | 6.02    |
|                | 50–59                                          | 448    | 0.71    |
|                | 60 years and older                             | 7,818  | 12.45   |
|                | Child<6years                                   | 27,158 | 43.26   |
| Occupation     | Self-Employed                                  | 10,674 | 17.00   |
|                | Student                                        | 10,852 | 17.28   |
|                | Housewife                                      | 10,954 | 17.45   |
|                | Food Service and Distribution Establishments   | 180    | 0.29    |
|                | Military Installations and Garrisons           | 240    | 0.38    |
|                | Agricultural Worker (farmer and rancher, etc.) | 2,727  | 4.34    |

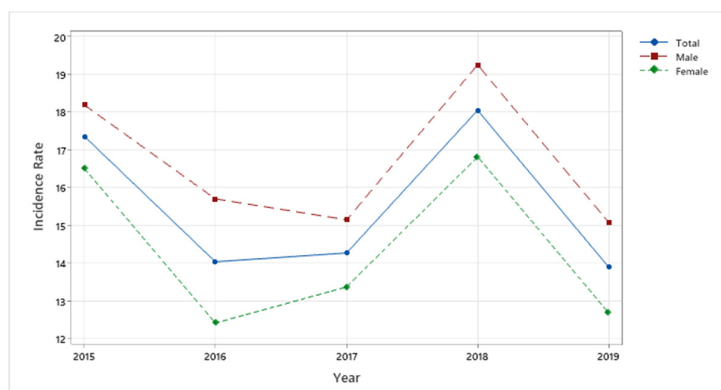


Figure 1. Trend of annual incidence rate of BDS in Iran by gender, 2015-2019



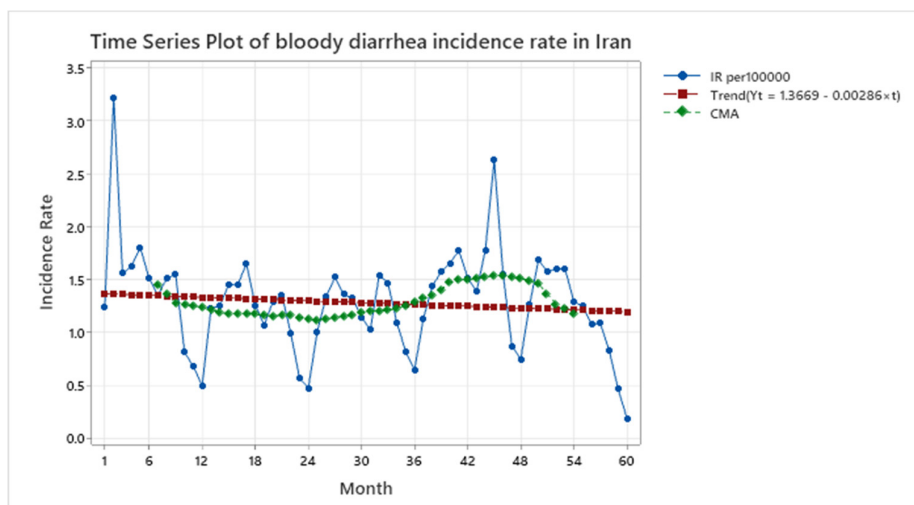


Figure 2. Trend and seasonal variation of bloody diarrhea rate in Iran, between 21 March 2015 and 19 March 2020

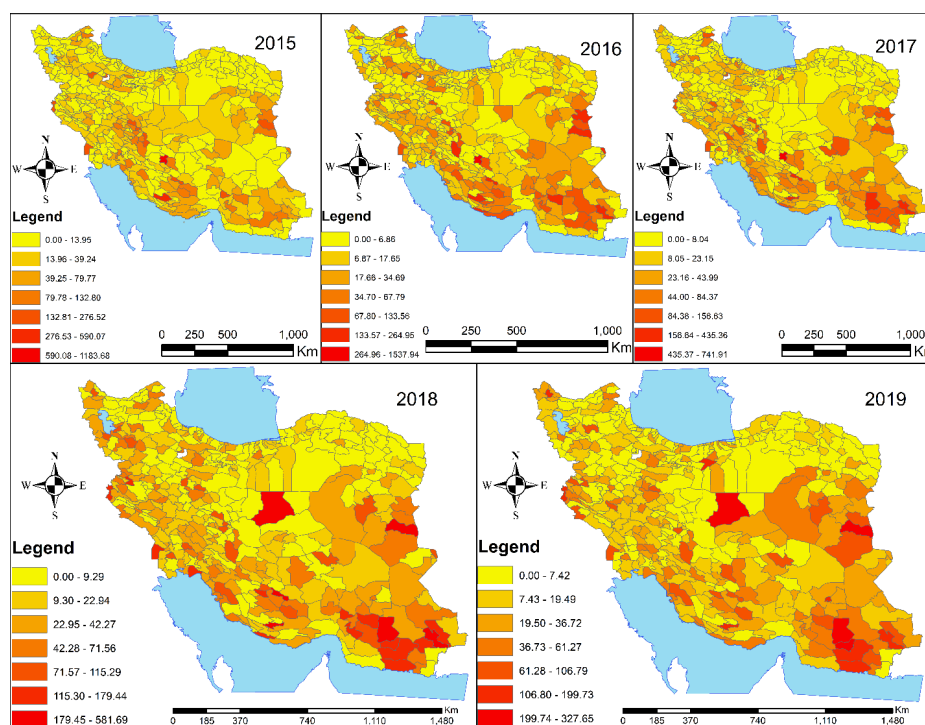


Figure 3. Distribution of bloody diarrhea incidence rate during 2015-2019.

spatial autocorrelation, confirming a clustered pattern in disease incidence. This clustering persisted across all study years except 2016, which exhibited a random spatial pattern (Figure 4).

#### Local Spatial Analysis

a) *Hot Spot Analysis (Getis-Ord Gi)\**: The Getis-Ord Gi\* statistic identified three primary high-incidence clusters (hot spots) at the 99% confidence level:

*Central Zone*: Encompassing parts of Fars and Yazd provinces.

*Southern Zone*: Covering areas within Fars, Hormozgan, and Bushehr provinces.

*Southeastern Zone*: Spanning large sections of Kerman, Sistan and Baluchestan, and South Khorasan provinces.

Lower-confidence hot spots (90–95%) were typically detected adjacent to these primary zones. Conversely, significant cold spots (low-incidence clusters) emerged from 2017 onward, predominantly concentrated in the northern provinces, including Tehran, Alborz, Mazandaran, Gilan, Golestan, and Khorasan Razavi.

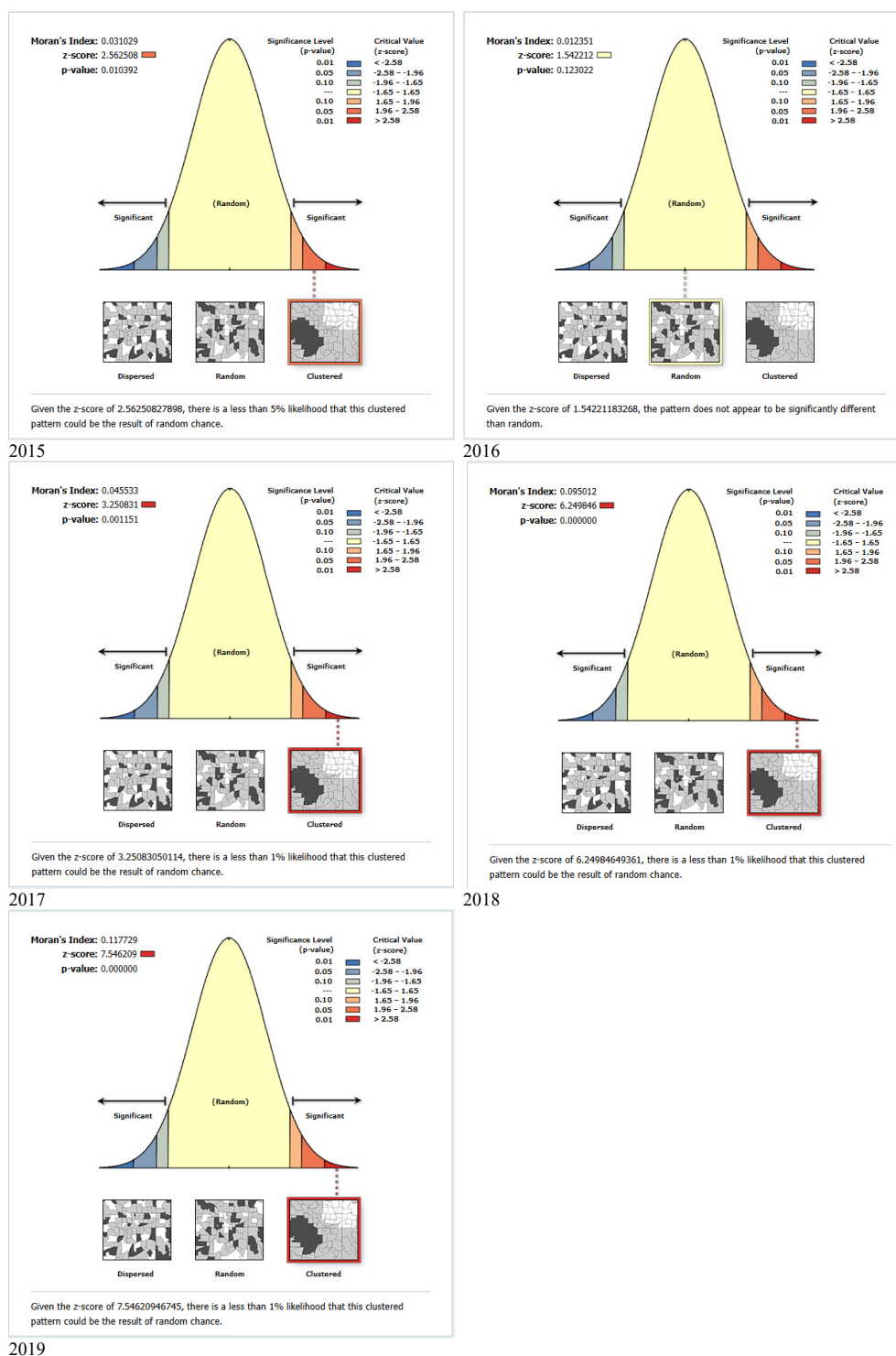


Figure 4. Results of the Global Spatial Autocorrelation (Moran's I) analysis for the county-level incidence of bloody diarrhea in Iran, (2015-2019).

The temporal persistence of these clusters varied significantly. The Isfahan and Chaharmahal-Bakhtiari hot spot was ephemeral, appearing only in 2015. In contrast, the Fars cluster remained stable until 2017, and the South Khorasan cluster persisted until 2019. Meanwhile, the

Sistan-Baluchestan and Kerman clusters remained consistently active from 2017 through the end of the study.

Notably, in 2019, a new isolated hot spot (95% confidence) was identified in Qasr-e Shirin county (Kerman-shah province) in western Iran (Figure 5).

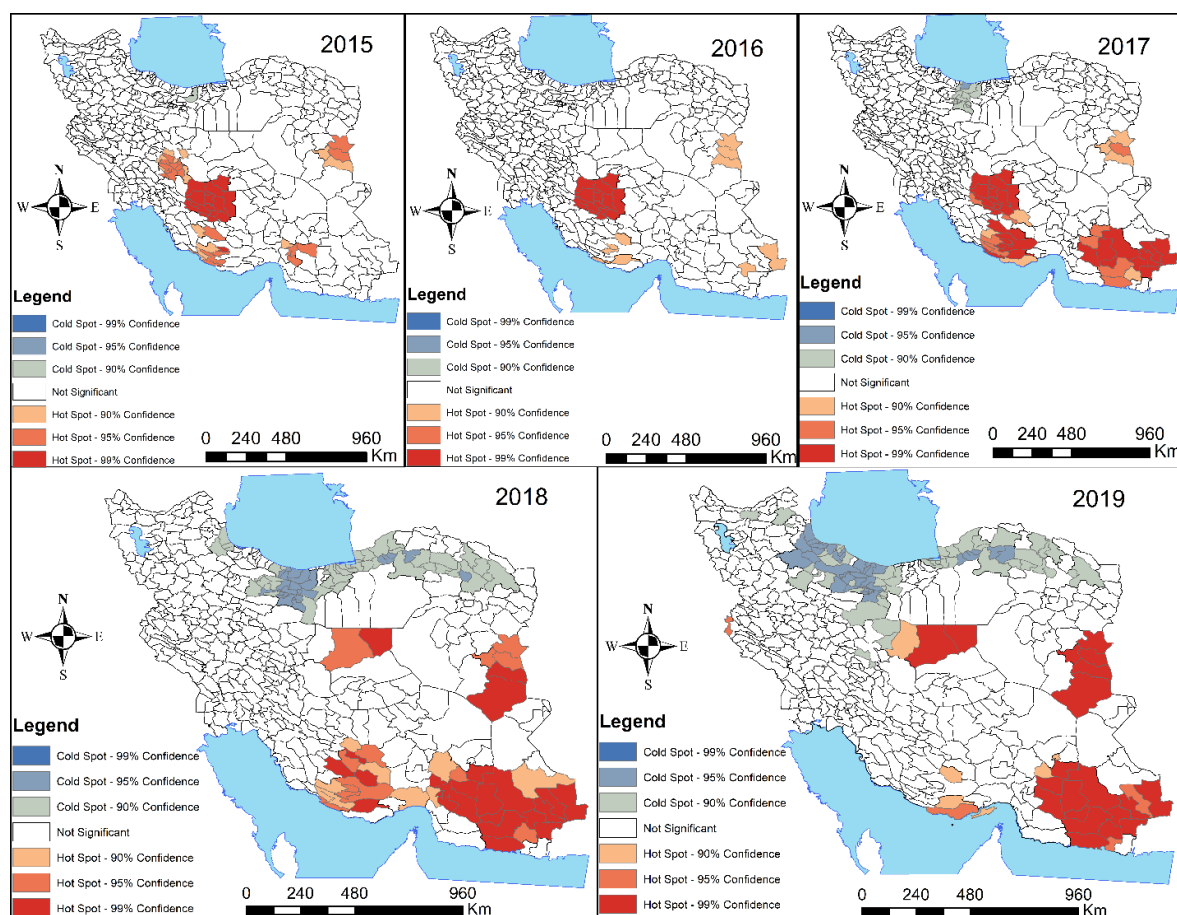


Figure 5. Geographical distribution of hot and cold spots for BDS in Iran, identified by the Getis-Ord Gi statistic (2015-2019).

b) *Cluster and Outlier Analysis (Anselin Local Moran's I)*: While corroborating the hot spots identified by the Gi\* statistic, this analysis provided more granular insights into the disease's spatial structure (Figure 6).

**High-High (HH) Clusters:** These clusters spatially coincided with the Gi\* hot spots. Sarbisheh (South Khorasan) and Roudbar-e Jonub (Kerman) counties were consistently classified as HH, joined by Zarrindasht (Fars) from 2016 onward.

**Low-Low (LL) Clusters:** No significant Low-Low clusters were detected nationwide during the study period.

**Spatial Outliers:** Several High-Low (HL) outliers were identified, representing isolated high-incidence areas surrounded by low-incidence neighbors—a spatial nuance not detectable by the Gi statistic\*. These included Taleqan, Khorrambid, and Khonj (2015); Semirom and Khorrambid (2016–2017); Komijan and Nain (2018); and Firouzkouh, Hashtroud, and Nain (2019). Additionally, 11 counties were identified as Low-High (LH) outliers, notably concentrated in Fars and Yazd provinces (mainly in 2016).

## Discussion

This study presents a comprehensive spatio-temporal analysis of BDS incidence at the national level over a

five-year period. Our findings reveal a distinct “epidemiological shift” in the disease’s geographical pattern—moving from the central to the southeastern regions of the country—concurrent with an overall downward trend in incidence. However, the identification of persistent hotspots and multiple outliers suggests that the decline in overall incidence does not equate to the elimination of risk; rather, it indicates that the disease is becoming “localized” within specific areas characterized by high vulnerability.

## Demographic Profile and High-Risk Groups

Demographic findings indicated that dysentery syndrome disproportionately affects children under 9 years of age, particularly those under 6. This finding aligns with global patterns of Shigellosis in developing countries, where immature immune systems and unhygienic behaviors (such as hand-to-mouth contact) play a pivotal role in fecal-oral transmission (19, 27).

A noteworthy observation is the substantial proportion of homemakers (17.45%) among the cases. Given that women in Iranian culture typically bear the primary responsibility for food preparation and caregiving for sick children, this group may function as both “victims” (through direct contact with infected children) and

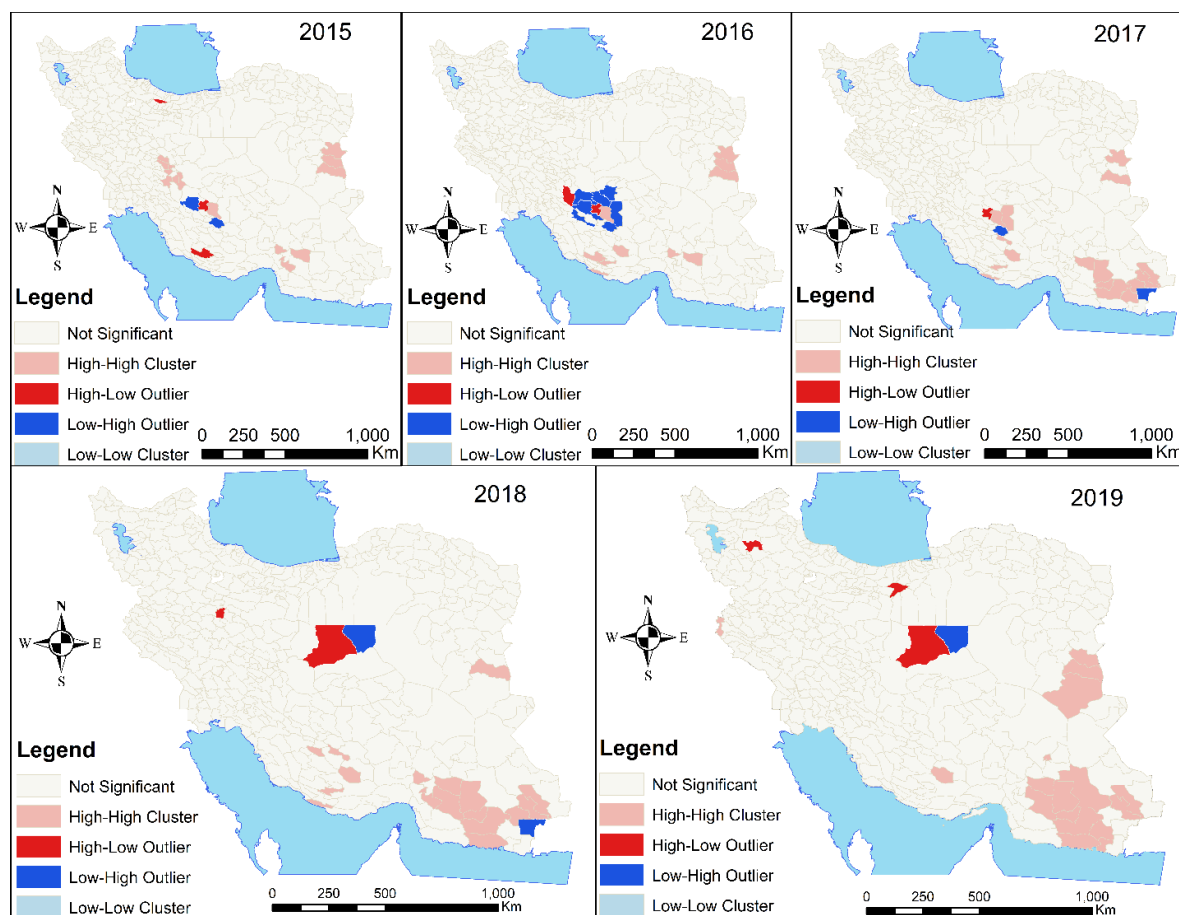


Figure 6. Clusters and spatial outliers in BDS Rate, 2015-2019.

“transmitters” (via food cross-contamination) within the household transmission cycle (6). Furthermore, the predominance of urban cases (65%) may reflect “reporting bias” stemming from better access to healthcare facilities and more rigorous registration systems in urban areas, rather than indicating a genuinely higher risk compared to rural regions.

#### Seasonal Patterns

Time series analysis, after adjusting for seasonality, revealed a very mild downward trend. This gradual decline may indicate relative improvements in water and sanitation infrastructure and enhanced health literacy; however, the Shallow slope serves as a warning that underlying risk factors persist.

The seasonal peak observed in May stands in contrast to some studies reporting the height of bacterial diarrhea incidence during the peak summer heat (28). This May peak is likely associated with increased spring travel, seasonal rainfall, and subsequent contamination of surface water sources. Furthermore, a major dysentery outbreak recorded between April 17 and May 5, 2015 (late Farvardin to mid-Ordibehesht), in Isfahan and Chaharmahal and Bakhtiari provinces significantly contributed to the elevated incidence in May (12, 13).

Conversely, the nadir of incidence in March is likely attributable to colder temperatures and reduced environmental pathogen activity.

Findings from other countries highlight variations in temporal patterns. For instance, in China, the disease peaks in autumn and winter for children under 5, whereas for those over 15, the peak occurs in summer (28). Similarly, a study in Ethiopia reported the highest incidence in February and the lowest between July and November, although the overall trend in that country was increasing (14). These disparities underscore that seasonal patterns of infectious diarrhea are heavily influenced by host susceptibility, pathogen type, and local characteristics, including climate, cultural behaviors, travel patterns, water sources, and the status of public health infrastructure (28).

#### Spatial Structure: From Transient Clusters to Endemic Foci

Global spatial analysis (Global Moran's I) confirmed the presence of significant clustering in most years, a finding consistent with studies reporting clustered disease patterns in other parts of the world (27).

Hotspot analysis (Gi\*) and Cluster and Outlier analysis (HH) demonstrated high convergence in identifying high-risk foci. The concentration of persistent hot clusters in



the southeast (Sistan and Baluchestan, Kerman) and east (South Khorasan), particularly in counties such as Sarbisheh and Roudbar-e Jonub, suggests the existence of a “risk belt” along the country’s eastern borders. These regions, burdened with challenges such as a scarcity of sustainable water resources, low socio-economic development indices, a hot and dry climate, and proximity to endemic countries (Afghanistan and Pakistan), act as active foci for disease circulation and transmission. The persistence of these clusters indicates the establishment of endemicity in these areas, underscoring the necessity for cross-border interventions and the development of basic infrastructure in these underprivileged regions (27).

Extending this spatial pattern, the identification of High-High (HH) clusters in Zarrindasht County (Fars Province) during 2016–2019 and Parsian County (Hormozgan Province) during 2016–2018 signifies the expansion of high-incidence foci toward the southern regions of the country. The geographical location of Zarrindasht in southeastern Fars and its border with Hormozgan, combined with the coastal position and Sea border of Parsian, suggests that disease dynamics may extend beyond the eastern borders, persisting along the Fars–Hormozgan axis and the southern coastal strip. This raises the possibility that environmental factors, access to safe water, and population movements play a significant role in these areas.

In contrast, the dissipation of hotspots in Isfahan and Chaharmahal and Bakhtiari provinces after 2015 likely reflects the success of targeted interventions or the containment of sporadic outbreaks in these central provinces (12, 13). Alongside these persistent and fading patterns, the emergence of a solitary hotspot (HH) in Qasr-e Shirin County on the western border indicates that western frontiers also possess the potential to evolve into new foci. This emerging cluster may be attributable to factors such as cross-border traffic with Iraq—especially during religious mass gatherings—or local waterborne outbreaks. This finding emphasizes the imperative of reinforcing the disease surveillance system across all border regions, not merely the eastern frontiers.

#### **The 2016 Paradox: High Intensity, Low Correlation**

The discrepancy between the results of hotspot analysis ( $G_i^*$ ) and Anselin Local Moran’s  $I$  in 2016 offers a profound insight into the disease distribution dynamics of that year. While the  $G_i^*$  test identified an extensive hotspot with 99% confidence across Fars and Yazd provinces, the LISA analysis failed to confirm a coherent High-High (HH) cluster in this region. Instead, it revealed a combination of Low-High (LH) and High-Low (HL) outliers.

This apparent paradox stems from the intrinsic difference between the two statistical tests:  $G_i^*$  is sensitive to “intensity,” whereas Anselin Local Moran’s  $I$  is sensitive to “correlation.” The occurrence of high case counts in certain counties (e.g., Khorrambid, with an unprecedented incidence of 1,537 per 100,000) sharply elevated the regional mean, resulting in a positive  $G_i^*$ . However, the stark contrast between these figures and those of neighboring counties with low case counts generated high local variance and led to the formation of LH outliers. Conse-

quently, the non-significance of the Global Moran’s  $I$  index in 2016 is rooted precisely in this local heterogeneity.

In other words, while the disease distribution in the country’s central region was highly “intense” that year, it lacked a coherent clustered structure due to the patchy and non-uniform nature of the incidence. This “mosaic pattern,” characterized by a high number of LH outliers, is the hallmark of 2016, distinguishing it from the preceding and subsequent years.

#### **Spatial Outliers: Implications for Surveillance**

Counties identified as spatial outliers represent valuable findings for the disease surveillance system. The identification of counties with a High-Low (HL) outlier pattern—including Taleghan, Firuzkuh, Semrom, Hashtroud, Komijan, Khorrambid, Khonj, and Nain—indicates the presence of high-incidence foci within seemingly low-risk regions. Unlike the extensive clusters in the southeast and east, which are primarily rooted in systemic regional and infrastructural challenges, these isolated foci are often observed in touristic or summer resort areas. This phenomenon is likely linked to seasonal population influx and the subsequent strain on local water resources.

On the other end of the spectrum, the identification of 11 counties as Low-High (LH) outliers is epidemiologically noteworthy. This pattern may reflect the presence of local protective factors, such as access to safer water sources, better sanitation infrastructure, or more effective implementation of control programs. Concurrently, it also raises the possibility of deficiencies in the reporting system and an underestimation of the true disease incidence. Therefore, these areas either represent replicable models of success or, due to their position amidst high-incidence counties, they possess an ecological potential for future outbreaks and thus require immediate strengthening of surveillance and active monitoring.

#### **The Situation in the North: Cold Spots and a Lack of Spatial Correlation**

The concentration of cold spots ( $G_i^*$ ) in the northern and north-central provinces of the country (including Tehran, Alborz, Gilan, Mazandaran, Golestan, and Razavi Khorasan) from 2017 onwards is a reflection of national developmental disparities. The low incidence rates in metropolises like Tehran and Karaj, as well as in the northern provinces, are likely attributable to better access to treated drinking water, higher sanitation network coverage, and a superior Human Development Index (HDI) compared to the southeastern border regions.

However, the Anselin Local Moran’s  $I$  analysis, designed by Anselin to assess local spatial correlation (25), revealed a critical nuance: all these cold-spot areas were classified as “Not Significant” rather than forming coherent Low-Low (LL) clusters. This finding indicates that although the overall disease incidence is low in these regions, this low rate lacks a coherent, correlated spatial structure. Instead, it stems from a random and scattered distribution of cases, a pattern characteristic of areas with widespread public health infrastructure (27).

Essentially, from a “global” perspective, the  $G_i^*$  test highlights the low incidence in the north relative to the national average (which is skewed by outbreaks in the south), thereby exposing inequality. Conversely, from a “local” perspective, the Anselin Local Moran’s  $I$  test demonstrates that this low incidence in the north is neither an exceptional phenomenon (an outlier) nor a distinct cluster. Rather, it is the product of a random dispersion of a few cases across a geographic landscape where a well-established health infrastructure has prevented the disease from forming clustered foci. In other words, the north is not characterized by “islands of purity” but rather by a “level plain” upon which the disease has been unable to gain a foothold and form clusters.

### Strengths and Limitations

This is the first comprehensive study in Iran to analyze the spatiotemporal changes in the incidence of bloody diarrhea syndrome at the county level over a five-year period. The primary strength of this research is the simultaneous application of advanced spatial statistical tools ( $G_i^*$  and Anselin Local Moran’s  $I$ ) to precisely identify hotspots, cold spots, and spatial outliers on a national scale, thereby providing a more detailed picture of the disease’s geographical heterogeneity.

Nevertheless, the study faced several limitations, primarily stemming from the nature of the surveillance data. First, the case definition used was based on syndromic reporting rather than laboratory confirmation. This means that the data do not differentiate between the various etiologies of dysentery (e.g., *Shigella*, *Campylobacter*, or *EHEC*), and the observed spatial patterns may reflect a composite of multiple causative agents.

Second, the data are based on a passive surveillance system, which is inherently prone to the challenge of under-reporting. Since patients with mild symptoms may not seek medical care, the calculated incidence rates should be considered a conservative estimate of the true disease burden in the community.

Third, the lack of access to homogenous, county-level environmental and climatic data (such as temperature, precipitation, and water quality) precluded a detailed ecological correlation analysis between these variables and disease incidence.

### Future Directions

It is recommended that future studies employ spatial regression models to quantify the impact of climatic and infrastructural variables on the disease distribution pattern. Furthermore, research focusing on counties identified as spatial outliers (particularly Low-High outliers) could provide valuable insights into the protective factors and successful management strategies in areas that have maintained low incidence rates, in contrast to their neighbors. Additionally, regarding temporal analysis, future research should incorporate harmonic terms (sine and cosine) into regression models. While the current study utilized deseasonalized time series with centered moving averages to identify peaks and secular trends, the inclusion of harmonic terms represents would provide a more robust approach

for developing predictive models and forecasting future outbreaks.

### Conclusion

The findings of this study revealed that the distribution of dysentery syndrome in Iran is highly heterogeneous. While hotspots are predominantly concentrated in the eastern belt and central regions of the country, the identification of spatial outliers in seemingly low-risk areas serves as a critical warning regarding the potential for localized outbreaks. Furthermore, the significant disease burden among children and homemakers underscores the key role of household transmission and hygienic practices.

Therefore, it is imperative for health policymakers to shift from one-size-fits-all approaches towards place-based strategies. Prioritizing the allocation of infrastructural resources to hotspots and establishing an early warning system in identified outlier locations are essential for effective outbreak management and the reduction of health disparities across the country.

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### Conflict of Interests

The authors declare that they have no competing interests.

### Authors’ Contributions

DB and BE conceived and designed the study. DB performed the data analysis and wrote the primary draft of the manuscript. MK and MS advised on the statistical analysis and methodology. MN and MZ contributed to data acquisition and interpretation. All authors critically reviewed the manuscript and approved the final version for publication.

### Ethical Considerations

This study was approved by the Research Ethics Committee of Iran University of Medical Sciences, with the number IR.IUMS.REC.1402.761. The recorded information of patients was kept confidential, and all data were completely anonymized before access. This research was conducted in accordance with ethical principles and national norms and standards for conducting medical research in Iran.

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### Data Availability

Data is available by contacting the corresponding author

### AI Use Statement

During the preparation of this work, the authors used Gemini Pro 2.1 to translate the initial drafts from Persian to English. Subsequently, EditGPT was used to edit the text, correct grammar, and enhance the overall readability of the English language. After using these tools, the authors closely reviewed and edited the content, verified all factual statements and references, and take full responsibility for the accuracy, originality, and integrity of the final submitted manuscript.

### References

- Bawankule R, Shetye S, Singh A, Singh A, Kumar K. Epidemiological investigation and management of bloody diarrhea among children in India. *PloS One*. 2019;14(9):e0222208.
- Osei FB, Stein A. Spatial variation and hot-spots of district level diarrhea incidences in Ghana: 2010–2014. *BMC Public Health*. 2017;17(1):617.
- Mikhail AF, Pereboom M, Utsi L, Hawker J, Lighthill J, Aird H, et al. Utility of whole-genome sequencing during an investigation of multiple foodborne outbreaks of *Shigella sonnei*. *Epidemiol Infect*. 2021;149:e71.
- Taneja N, Nato F, Darteville S, Sire JM, Garin B, Thi Phuong LN, et al. Dipstick test for rapid diagnosis of *Shigella dysenteriae* 1 in bacterial cultures and its potential use on stool samples. *PLoS One*. 2011;6(10):e24830.
- Hendrick J, Raqib R, Noor Z, Faruque ASG, Haque R, Petri WA. Shigellosis. *Lancet*. 2025;406(10511):1508-19.
- Taneja N, Mewara A. Shigellosis: Epidemiology in India. *Indian J Med Res*. 2016;143(5):565-76.
- Tan X, Li J, Li W, Liu X. Dynamic analysis of diffusion dysentery diarrhoea epidemic model. *Commun Nonlinear Sci Numer Simul*. 2025;109245.
- Hu K, Yang X, Ou S, Li C, Zhang X, Xiao D, et al. A multi-method spatial analysis of dysentery incidence determinants across Chinese provinces. *Front Public Health*. 2025;13:1663473.
- Yang J, Chen W, Xia P, Zhang W. Dynamic comparison of gut microbiota of mice infected with *Shigella flexneri* via two different infective routes. *Exp Ther Med*. 2020;19(3):2273-81.
- Xiao G, Xu C, Wang J, Yang D, Wang L. Spatial-temporal pattern and risk factor analysis of bacillary dysentery in the Beijing-Tianjin-Tangshan urban region of China. *BMC public health*. 2014;14(1):998.
- Li R, Lai Y, Feng C, Dev R, Wang Y, Hao Y. Diarrhea in under five year-old children in Nepal: a spatiotemporal analysis based on demographic and health survey data. *Int J Environ Res Public Health*. 2020;17(6):2140.
- Torabi Z, Nematollahi S, Ahmadnezhad E, Holakoe Naieni K. An Epidemic of *Shigella Flexneri* and its Related Factors in Isfahan in Spring 2015: A Case –Control Study. *Iran J Epidemiol*. 2018;14(2):177-86.
- Taheri SM, Tabatabaei SM, Lotfi MH, Ghaderi A, Jazayeri SR, Reisi A. Evaluating the Status of Patients Suffering from Diarrhea During the Outbreak Occurred in Shahrekord in 2015. 2016. *J Community Health Res*. 2016;5(1): 11-19.
- Beyene H, Deressa W, Kumie A, Grace D. Spatial, temporal, and spatiotemporal analysis of under-five diarrhea in Southern Ethiopia. *Trop Med Health*. 2018;46(1):18.
- Lin CH, Wen TH. How Spatial Epidemiology Helps Understand Infectious Human Disease Transmission. *Trop Med Infect Dis*. 2022;7(8).
- Nadi A, Abedi G, Isazadeh K, Rostami F, Siamian H, Hosseini M, et al. Epidemiologic investigation of dysentery in north of Iran: use of geographic information system (GIS). *Mater Socio-Med*. 2016;28(6):444.
- Khoubfekar H, Shayesteh M, Sharafi I, Rahmanian V. Epidemiology of dysentery in South Khorasan province, Iran (2016-2020). *J Prev Complement Med*. 2022;1(2):101-7.
- Khosravi AD, Khaghani S, Sheikh AF, Ahmadzadeh A, Shamsizadeh A. Prevalence of *Escherichia coli* O157: H7 in children with bloody diarrhea referring to Abuzar teaching hospital, Ahvaz, Iran. *J Clin Diagn Res: JCDR*. 2016;10(1):DC13.
- Sheikh AF, Moosavian M, Abdi M, Heidary M, Shahi F, Jomehzadeh N, et al. Prevalence and antimicrobial resistance of *Shigella* species isolated from diarrheal patients in Ahvaz, southwest Iran. *Infect Drug Resist*. 2019:249-53.
- Khan D, Rossen LM, Hamilton BE, He Y, Wei R, Dienes E. Hot spots, cluster detection and spatial outlier analysis of teen birth rates in the US, 2003–2012. *Spat Spatiotemporal Epidemiol*. 2017;21:67-75.
- World Mo. Iran Latitude and Longitude Map 2025 [Available from: [https://www.mapsofworld.com/lat\\_long/iran-lat-long.html](https://www.mapsofworld.com/lat_long/iran-lat-long.html)].
- Holakouie-Naieni K, Mostafavi E, Boloorani AD, Mohebbi M, Pakzad R. Spatial modeling of cutaneous leishmaniasis in Iran from 1983 to 2013. *Acta Trop*. 2017;166:67-73.
- Institute ESR. Spatial Autocorrelation (Global Moran's I) 2012 [Available from: [https://resources.arcgis.com/en/help/main/10.1/index.html#/Spatial\\_Autocorrelation\\_Global\\_Moran\\_s\\_I/005p000000n000000/](https://resources.arcgis.com/en/help/main/10.1/index.html#/Spatial_Autocorrelation_Global_Moran_s_I/005p000000n000000/)].
- Pakzad R, Pakzad I, Safiri S, Shirzadi MR, Mohammadpour M, Behrooz A, et al. Spatiotemporal analysis of brucellosis incidence in Iran from 2011 to 2014 using GIS. *Int J Infect Dis*. 2018;67:129-36.
- Anselin L. Local indicators of spatial association—LISA. *Geogr Anal*. 1995;27(2):93-115.
- Institute ESR. ArcGIS Help: Fundamentals 2012 [Available from: <https://resources.arcgis.com/en/help/main/10.1/index.html#/005p000000z0000000/>].
- Zhang H, Si Y, Wang X, Gong P. Environmental Drivers and Predicted Risk of Bacillary Dysentery in Southwest China. *Int J Environ Res Public Health*. 2017;14(7).
- Xu Z, Hu W, Zhang Y, Wang X, Zhou M, Su H, et al. Exploration of diarrhoea seasonality and its drivers in China. *Sci Rep*. 2015;5(1):8241.